WATER RESOURCES BOARD

Report
on
Desalination for England and Wales

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I. INTRODUCTION

1. The Water Resources Board have a duty under section 12 of the Water Resources Act 1963 to consider what action is needed to augment water resources in England and Wales, and section 135(4) of the Act explicitly includes action for the purpose of treating salt water (whether taken from the sea or elsewhere) by any process for removing salt or other impurities before introducing it into a source of supply.

2. Accordingly, on its establishment in 1964 the Board took over from the then Department of Scientific and Industrial Research a three year agreement with the Water Research Association for a feasibility study on the application of desalination to water supply in England and Wales. That study has recently been completed and the results published by the Association in an interim report (T.P. 50) (1) and their final report (T.P. 60) (2). Later in 1964 the Board set up a co-ordinating committee on which are now represented the U.K. Atomic Energy Authority, Central Electricity Generating Board, Water Research Association, Water Pollution Research Laboratory, Electricity Council and Ministry of Technology. In late 1964 the Board appointed consultants to study the technical and economic problems involved in providing a 10 million gallons per day (m.g.d.) demonstration distillation unit in the East Essex area and on the completion of that study the Board retained the consultants to advise them on general technical and economic desalination questions. The research and development programme guided by the U.K. Atomic Energy Authority involves expenditure of over £1 million a year to which must be added substantial effort by industry.

3. This report sets out the Board's views on the application of desalination in England and Wales. The Board have drawn on the information provided by the Water Research Association in their two reports and on the advice of their desalination co-ordinating committee and of their consultants.

4. In discussing the different desalination processes, this report frequently refers to a time when those processes might become economic. This is intended to mean no more than the time when their costs have reached near parity with those of obtaining water from other sources. In any particular case there may be other factors which may make a more expensive process worth adopting.

II. WATER RESOURCE DEVELOPMENT

5. The Water Resources Act 1963 provided the basis for the comprehensive management of water resources in England and Wales. The 29 river authorities, which were set up under the Act, took over the land drainage, fisheries, river pollution and, where appropriate, navigation functions of the former river boards. In addition they were made responsible for the control and development of the water resources, both surface and underground, within their area. Control is effected by a licensing system and holders of licences are subject to charges which are used to meet the expenses incurred by river authorities in carrying out their water resources functions.

6. In accordance with their responsibilities under the 1963 Act and to assist in the formulation of an integrated national policy the Board commenced in late 1964 a study of the future demands in South East England and of the resources available to meet those demands. The Board's report "Water Supplies in South East England" (3) was published in 1966. It gave estimates of demands throughout the region broken down into river authority areas for the years 1971, 1981 and 2001 and identified the types of schemes the Board considered necessary to meet those demands.

7. A similar study has now been completed for the North of England, and one for Wales and the Midlands is in progress.

8. Future demands when totalled over a region involve quantities so great that very large schemes can be contemplated. These include regulating reservoirs to make possible the transfer of water from the wet northern and western areas into the headwaters of rivers running south and east and the development of estuarial storage. Such schemes will use land much more economically than in the past.

9. A national approach to water resources provides the opportunity to consider new concepts of augmenting water resources in England and Wales such as artificial recharge of underground storage, estuarial storage and desalination. Furthermore a better knowledge becomes available of where and under what conditions such techniques are likely to be of value.

III. DESALINATION PROCESSES

Distillation

10. All distillation processes operate by boiling sea water and condensing the salt free steam. Two types of plant are used, multi-stage flasb distillation and long tube vertical distillation. Botb types can be operated independently or linked with a power station. In this report the former are referred to as single purpose plants and the latter as dual purpose plants.

Multi-stage flash distillation (M.S.F.)

11. Many M.S.F. distillation plants have been constructed or are under construction througbout the world. Tbe largest single unit so far built has an output of 4 m.g.d. but manufacturers are now able to build units of up to 10 m.g.d. capacity. Clearly therefore tbe process can be accepted as a proved means of sea water desalination. Tbe only plant yet built in tbe British Isles for public water supply is in Guernsey. This has an output of 0·5 m.g.d. and was built to ensure water for the valuable tomato crop in times of drougbt. It bas so far rarely been put to use. A 1·5 m.g.d. plant is now being built in Jersey to augment the supplies of water for drinking and other purposes.

12. Tbe process operates by beating sea water under pressure to a high temperature. Tbe bot brine then passes througb a series of chambers wbere the pressure is successively reduced. In eacb chamber a portion of the brine flasbes (i.e. boils instantaneously) to give a salt free steam. This steam is condensed in banks of condensers whicb pre-beat the incoming sea water.

13. The source of heat for sucb a plant is low pressure steam. This may be produced in a low pressure boiler for the single purpose of distillation or it may be extracted from the turbine system of a power station in a dual purpose installation for electricity generation and distillation. In the single-purpose plant the cost of steam is almost independent of pressure and lower water costs result from operating distillation plant at high temperature. Scale formation sets a limit to temperature. With the use of a polyphospbate sequestering agent the upper temperature limit is about 190°F; but in the United Kingdom pre-treatment for pH control using acid, which is relatively cheap in this country, enables temperatures up to about 250°F to be used. Above this temperature calcium sulphate scaling occurs and pH control has no effect. Present development effort is directed towards improvements in scale control, beat transfer and flashing cbaracteristics largely with the aim of reducing capital costs.

14. An advantage of multi-stage flash distillation is flexibility in design. A plant can be constructed to obtain an optimum balance of capital and operating costs for the circumstances under whicb it will be operated. For example, a plant to operate at a low load factor would be designed as a low capital cost installation baving high operating costs.

Long tube vertical distillation (L.T.V.)

15. This is a multiple effect process where the steam generated in one effect condenses on the outside of long vertical tubes in the subsequent effect thus evaporating more water from the film of sea water falling down the inside surface of the tubes. This process has not yet been widely used, only one large plant (0·8 m.g.d.) having so far been constructed. Present indications are that it is competitive with M.S.F. distillation and will become more generally adopted. Certainly the development of double fluted tubes and improved layout will lead to costs lower than those experienced at the United States demonstration plant at Freeport, Texas (4). The process probably has greater potential than the M.S.F. distillation process for cost reductions in the future (5).

Water quality

16. Distillation plants are located mainly where good quality sea water is available. Some estuarial waters cannot be treated by the distillation process as the contaminants cause unacceptable corrosion and fouling of heat exchange surfaces, and volatile components may vaporise and contaminate the distillate. The limits of contamination which can be tolerated are not well known and hence plant manufacturers are often reluctant to guarantee units fed from polluted sources. However a small unit (0·046 m.g.d.) for industry is located at Canvey Island in the Thames Estuary and is reported to be operating successfully even though the quality of the sea water is poor.

17. Unless precautions are taken the water produced by distillation plants may cause difficulties when put into supply. In the United Kingdom water would be likely to leave a distillation plant at a temperature of about 80–85°F and be almost free of hardness. Cooling could be achieved at little cost, but if the cooled water was passed through cast iron, steel or asbestos cement mains at only a slightly higher temperature than water obtained from natural sources, the mains might become corroded and existing deposits in the mains removed. The resultant problems might be serious.

18. In some cases these problems could be avoided at a very small cost by blending the distilled water with water from a natural source. It might also be possible to avoid softening treatment of water from a natural source by blending it with distilled water, thus softening and augmenting the supply at the same time. If blending proved impractical, treatment of the distilled water would have to be undertaken; the addition of a little hardness and the adjustment of pH should render the water passive. However, insufficient experience exists at present to be confident that these procedures, particularly the blending of distilled water with natural water, would prove successful. The Board hope shortly to carry out research into the integration of distilled and natural waters.

Electrodialysis

19. Electrodialysis is the only desalination process other than multi-stage flash distillation which is in proved commercial use, but not for sea water. Over 150 plants, most of them small, have been installed for the desalination

of brackish water (6). Electrodialysis involves the passage of an electric current through brackish water in a tank in which many closely spaced membranes are inserted to divide the tank into compartments. The current causes the salts to be concentrated in alternate compartments with relatively salt free water in the remainder.

20. The largest unit is of 0·54 m.g.d. but the majority of plants constructed to date are less than one tenth this size. There is little difficulty, however, in building very large plants since these involve only the duplication of smaller units. Particularly successful development work has been conducted in the United Kingdom during the last few years and significant cost reductions have been achieved. Capital costs have been reduced by about 40 per cent by simplifying stack design and construction and by using the area of membranes more efficiently.

Water quality

21. It will be seen from Chapter V that the cost of treating low salinity waters (less than 2,000 ppm of total dissolved solids (T.D.S.)) by electrodialysis is low compared with the costs of distillation, if a product with 500 ppm T.D.S. is acceptable. This would be quite acceptable if the impurity were mostly hardness, but if it were sodium chloride, this could not be passed into a distribution system without first blending with good quality water from a natural source. Thus the nature of the salinity influences the linking costs (see paragraph 51 below) and in some cases these will be high.

22. A potential use of electrodialysis in England and Wales which has not yet been sufficiently explored is for treating industrial and municipal wastes. Organic contaminants are known to interfere with the operation of electrodialysis units, but as an extra stage of a conventional sewage treatment process electrodialysis might prove economic in removing relatively small quantities of undesirable dissolved salts. Such applications of electrodialysis warrant investigation.

Reverse Osmosis

23. Reverse osmosis appears to be the most promising of the developing desalination processes for the treatment of low and medium salinity waters as well as industrial and municipal effluents. Only since late 1966 have units been available commercially and no British made plant is yet available. The largest plant constructed is of 0·05 m.g.d. capacity but as with electrodialysis relatively little difficulty exists in providing large plants by duplicating small units.

24. When salt water and fresh water are separated by a semi-permeable membrane osmotic pressure forces the fresh water through the membrane to dilute the salt water. In the reverse osmosis process a higher pressure is applied to the salt water so that pure water is forced out of it into the fresh water leaving behind a more concentrated salt water. The success of the process depends entirely on the characteristics of the cellulose acetate membranes and the development of a practical membrane support which can withstand pressures of 500–1,000 pounds per square inch (p.s.i.) and still permit water to pass. Several membrane support systems are being developed, flat plate, tubular and spirally wound units being examples.

25. The membranes in current use have various properties depending upon the method of fabrication. Some membranes have a high salt rejection and low flux (i.e. low rate of movement of water through the membrane); these are most suited to medium salinity waters e.g. 5,000–10,000 ppm T.D.S. Lower salt rejection high flux membranes are better suited to the removal of a few hundred ppm of dissolved solids.

26. Until the treatment of brackish water has been demonstrated as reliable, sea water conversion by this process must be regarded as a long term development. However, desalination of sea water using a two stage process has been accomplished, and it is reported that membranes have been produced which are suitable for single stage conversion.

Water quality

27. A most important characteristic of present reverse osmosis membranes is that they are effective with a wide range of solutes. Not only are the majority of inorganic salts separated, but large organic molecules are also rejected. This makes the process promising for the treatment of industrial and municipal effluents and in this field reverse osmosis is likely to find application in England and Wales.

The Freezing Processes

28. Two freezing processes are being developed, the vacuum process and the secondary refrigerant process.

The vacuum freezing process

29. In the vacuum freezing process salt water is subjected to low temperature and pressure to produce water vapour and a slurry of ice and brine. The vapour is compressed to raise its temperature and pressure and is then condensed by direct contact with the ice which has been washed and separated from the brine. The melted ice and condensed vapour produce the product water. The largest unit of this type has a capacity of 0·1 m.g.d.

The secondary refrigerant process

30. The secondary refrigerant process has the advantage of operating at higher pressures and hence compression problems are much less. However, the only large plant of this type, with a capacity of 0·17 m.g.d., has not proved successful and this held up development. Nevertheless pilot plant work in the United Kingdom is being carried out with some success.

Ion exchange

31. An ion exchange process is being developed in the United States and Italy for the removal of salt from mildly brackish waters. The process operates on a bicarbonate cycle with weak electrolyte resins. This technique is unlikely to be of importance as a general method of desalination but it may prove a useful means of removing a few hundred ppm of sodium chloride from water. The high cost of resin regeneration precludes the use of the process on all but waters containing small amounts of dissolved solids.

IV. APPLICATION OF DESALINATION

32. The main interest in desalination is for making sea water fit for general use for public water supply. The distillation process was developed for this purpose and is much used in arid countries. There are, however, other uses of desalination, some of which have more application at present in Britain than desalination of sea water. They fall into three categories:

(i) industrial use;

(ii) pollution control;

(iii) brackish water treatment.

(i) Industrial use

33. Desalination is already being used in the United Kingdom for specialised industrial purposes. More than 100 distillation plants have been installed to produce water for boiler feed at various power stations. In most of these distillation is used to remove the majority of dissolved solids from the raw water and this process is followed by ion exchange treatment for final polishing prior to entry into the boiler. In this way water which may be adequate for potable purposes is brought to the higher standard needed for high pressure boilers. Sea water can be similarly treated to the exceptionally high standards required.

34. Exceptionally pure water for medical purposes or for industrial use such as washing of television tubes is produced from potable water by ion exchange. The extraction or concentration of chemicals in trade effluents is also undertaken to recover valuable materials or to render an effluent acceptable in quality for discharge to local authority sewers. These types of applications do not normally contribute to our water resources.

(ii) Pollution control

35. At times the quality of some river waters falls below what is acceptable for treatment for public water supply by normal methods. Pollution of a river may not be serious during periods of high river flow but during low flow it may limit the full use of the river. Given provision for the disposal of the concentrated effluent produced, desalination could be used to improve the quality of such a river by treating some of the major sources of effluent at the factory or sewage works. The proven techniques of multi-stage flash distillation and electrodialysis can be used to treat some industrial wastes but the developing processes, particularly reverse osmosis, seem more promising for this type of application.

36. A factor which may well influence costs significantly is the disposal of the waste from the desalination process even assuming that it can be discharged to the sea. If 8 m.g.d. of polluted water is treated to give 6 m.g.d. of product water and 2 m.g.d. of highly concentrated waste, and this

waste has to be pumped 30 miles to the sea, the cost of waste disposal may amount to as much as 10d. per thousand gallons (p.t.g.) of the product water. In other situations, for example a factory sited on the sbores of an estuary, waste disposal may present no serious prohlems. Clearly these circumstances would strongly influence both tbe decision to desalinate and the design of the plant. In the first case, the incentive is to use a plant with a higb recovery ratio. Thus if reverse osmosis were used, the feed water salinity in the later stages of the plant would be higher and therefore some of the membranes sbould have high salt rejection properties and would he expected to bave a lower flux and shorter life. Where the recovery ratio is not important, a memhrane with lower salt rejection and higher flux could be used.

37. A rather different form of pollution of surface waters, and indeed of ground water, is arising. High nitrate concentrations are appearing in some lowland rivers, for example in Essex. This is partly due to increasing sewage content but the more extensive use of nitrogenous fertilisers also contributes. In the future it may be necessary to reduce tbe nitrate content of water ahstracted from certain rivers for public water supply, perhaps by desalination using reverse osmosis or electrodialysis.

38. A significant factor to note when considering desalination of any of these polluted sources, except wben tbe pollution is due to agricultural nitrate, is that pollution is in many cases minimal during periods of high river flow and hence desalting may well be required only at periods of low river flow. This should be borne in mind when developing treatment techniques as low capital cost plants would be preferable in these circumstances.

39. A largely untapped water resource exists in the form of municipal effluents discharged to estuaries. The possibility of having to use treated municipal effluents directly for potable supply is unlikely to arise for many years but treated effluents could he used by industry. Already sewage effluents are being used for cooling purposes.

40. Reverse osmosis and electrodialysis are suitable for the removal of dissolved inorganic salts and it appears from initial tests that reverse osmosis will be ahle to remove a wide range of organic contaminants. The Board have strongly supported proposals for a researcb programme on water reclamation hy reverse osmosis, and are pleased that such a programme is now being undertaken jointly by the Atomic Energy Research Establishment and the Water Pollution Research Laboratory with participation by the Board in seeking suitable applications.

(iii) Brackish water treatment

41. Electrodialysis has been specifically developed as a desalination process for the treatment of hrackish ground waters, and numerous plants bave been constructed ahroad for this purpose. Reverse osmosis is in a less advanced stage, but brackisb water conversion is the first goal for those working on this process. It is unlikely that brackish water conversion will ever contribute significantly to the water resources of England and Wales, because relatively few sources of brackish water exist there. However, isolated uses of electrodialysis for the treatment of brackish ground waters

may arise in the near future, also of reverse osmosis if the development work being pursued is successful. In some of the areas involved the brackish nature of the ground water is the result of sea water intrusion into fresh water aquifers. In such cases desalination may not be the answer ; it may be preferable to control the intrusion by better management of the aquifer.

42. The Board encouraged the installation of an electrodialysis pilot plant at Manningtree, Essex, which is now being used for the treatment of saline ground water. The successful operation of this unit has shown that there is no major problem in the treatment of such waters and has assisted in the development of probably one of the most advanced electrodialysis units yet in operation.

V. COSTS OF DESALINATION PROCESSES AND CONVENTIONAL WATER SUPPLY SCHEMES

43. Any costing of desalination and conventional water supply schemes on a general basis is obviously open to criticism because the circumstances of each specific scheme vary enormously. The distances over which the water would have to be distributed and the method of using a desalination process in conjunction with existing sources are but two examples of these differing circumstances.

44. Nevertheless, it is necessary to make a broad comparison of costs in order to assess the possibilities of applying desalination techniques in England and Wales. For this purpose we have adopted the basis used by the Water Research Association which is explained in detail in their publication T.P. 60 (2). All costs are at 1967 values and do not include the effect of devaluation which took place in November of that year.

Costing of desalination

45. *General assumptions made in assessment of desalination costs.*

Unless otherwise stated:—

(i) interest rate is 6·5 per cent, the rate used in costing conventional schemes ;

(ii) amortisation periods and fixed charges are as shown on Table No. 1 below. Loan sanction periods are likely if anything to be shorter than the amortisation periods quoted ;

(iii) fuel oil is costed at 4·5d. per therm (the present surcharge is not included) ;

(iv) load factor for base load is 90 per cent (330 days p.a.) ;

(v) electricity is costed at 1d. per kilowatt hour (kwh) ;

(vi) capital cost of low pressure steam raising plant is taken at £1 per lb./hr. of capacity.

TABLE No. 1

AMORTISATION PERIODS AND FIXED CHARGES USED IN ESTIMATING COST OF WATER PRODUCED BY DIFFERENT DESALINATION METHODS

Process	Amortisation Period	Fixed charges (capital)	Fixed charges (capital and maintenance)
		per cent	per cent
Distillation	20 years	9·1	12·0
Reverse osmosis ...	16 years	10·4	12·0
Electrodialysis ...	12·5 years	11·9	13·4
Other	20 years	9·1	12·0

Multi-stage flash distillation

46. A summary of costs is given in the Table No. 2 below.

TABLE No. 2

MULTI-STAGE FLASH DISTILLATION
ESTIMATED COST OF PRODUCT WATER EXCLUDING LINKING COSTS

	Total Water Cost (pence p.t.g.)			Capital Cost £ (million)		
Unit Capacity m.g.d. ...	3	10*	30*	3	10*	30*
Single purpose plant ...	97	85	77	1·6	4·5	11·1
Dual purpose plant (Steam cost 15–35d. per million Btu)	64–86	57–76	51–68	0·9–1·3	2·6–3·7	6·9–10·0

*The costs quoted are extrapolated from existing experience with smaller units and based on research studies.

Electrodialysis

47. The costs of treatment by electrodialysis are strongly influenced by the salinity of both the feed and product water. It becomes expensive to produce water with much less than 400 ppm total dissolved solids (T.D.S.) due to lower conductivities and increased polarisation in the compartments containing the product water. Similarly it is costly to treat high salinity water since the power consumption is almost proportional to the equivalents of salts to be removed. Electrodialysis of sea water (approximately 35,000 ppm of T.D.S.) is at present out of the question on cost and technical grounds.

48. A summary of costs is shown in Table No. 3 below. This demonstrates the effect of feed water salinity and plant size upon water costs and capital costs.

TABLE No. 3

ELECTRODIALYSIS
ESTIMATED COST OF PRODUCT WATER (500 PPM OF T.D.S.) EXCLUDING LINKING COSTS

Plant size m.g.d.	Total Water Cost (pence p.t.g.)			Capital Cost £ (thousand)		
	Feed Salinity ppm			Feed Salinity ppm		
	1000	2000	4000	1000	2000	4000
0·5	22	34	56	31	52	84
1·0	20	32	54	51	93	157
4·0	17	29	51	170	343	595

The costs quoted are based upon hand assembly of electrodialysis stacks. If the demand for this type of plant grows sufficiently to justify mechanical manufacture and assembly, costs can be expected to fall.

Reverse Osmosis

49. Since reverse osmosis is at an early stage of development, costs cannot be predicted with any degree of confidence. Likely costs suggested hy the Water Research Association are 50d. p.t.g. for the treatment of a brackish water of 5,000 ppm T.D.S. to give a product of about 300 ppm T.D.S. This figure is hased upon a working pressure of 700 psi, a memhrane flux of 15 gallons per square foot per day, a memhrane replacement cost of ahout 24d. per square foot and a one year memhrane life. Linking costs are again excluded. These hases are very conservative and it may well he found that costs well below 50d. p.t.g. will be achieved in the future.

Freezing processes

50. The largest vacuum freezing plant in operation has a capacity of 0·1 m.g.d. and produces water at a cost of ahout 100d. p.t.g. based on 12 per cent fixed charges, 90 per cent load factor and power cost of 1d. per kwh. Costs can be expected to fall as development proceeds, hut it is unlikely that they will become low enough to be of interest in England and Wales. Costs for the secondary refrigerant freezing process are not yet availahle, hut it is understood that the pilot plant work carried out in the United Kingdom has led to a favourahle costing of the process and further larger scale pilot plant work is now proceeding.

Linking costs

51. To ohtain a common basis for comparing desalination costs with conventional source costs it is necessary to add to the cost of desalted water the expense involved in its transport to the area of use, cost of storage and any special treatment costs which might need to be applied to it. Linking costs will differ widely according to the distance and elevation of the local supply in relation to the desalination plant and the special treatment needed. It is estimated that they may vary from almost zero to 18d. p.t.g.

52. To illustrate this, two hypothetical examples have been costed, both of sea water desalination on the coast, one of which involved the movement of the desalted water 5 miles with a pumping head of 200 feet, the other 10 miles with a pumping head of 300 feet. The respective linking costs, without making any allowance for treatment costs, worked out at 7d. p.t.g. and 16d. p.t.g. The distances used in these examples are comparatively short for the movement of water and illustrate the expensive nature of linking costs even over comparatively short distances.

Costing of conventional supply schemes

53. The costs which have heen estimated for conventional water supply schemes include all operations up to and including the service reservoir in a system but do not cover the distribution from the service reservoir to the consumer's premises. Linking costs are, therefore, already included in the costs of conventional schemes quoted in this report.

54. The Water Research Association estimated the cost of water from 24 conventional schemes, many carried out or proposed for construction during the period 1960–70. In none of these did the cost exceed 36d. p.t.g.

The basis on which the Association assessed the costs of these schemes is given in detail in their publication T.P. 60 (2). In broad terms an interest rate of 6½ per cent per annum was used for capital costs which were written off over the period for which loans were normally granted to water undertakings for water conservation schemes.

55. In the Board's report on "Water Supplies in South East England"(3) the estimated costs of water from schemes to meet demand to the end of the century were mostly below 36d. p.t.g. Costs for Essex were higher—up to 46d. and 47d. for water from the Thames and the Severn but these were quite exceptional. Over the country generally 36d. p.t.g. is unlikely to be exceeded this century. Nevertheless Essex is an area where desalination may first become competitive with the cost of importing water.

VI. ASSESSMENT OF POSSIBLE USE OF DESALINATION IN ENGLAND AND WALES

Base load desalination

56. A single purpose distillation plant, assuming a unit as big as 10 m.g.d. can be constructed and operated, producing water at a cost somewhere between 85d. and 97d. p.t.g. to which must be added the linking costs, is not competitive with conventional water supply schemes in any but the most special cases. For example an industrial demand for high quality water might justify these costs. In general costs of conventional water supply schemes are not expected to exceed 36d. p.t.g. delivered to the service reservoir during the present century, and this makes the single purpose distillation plant too expensive.

57. A dual purpose plant, however, can produce water more cheaply than a single purpose plant at the same load factor. The actual cost of steam produced in a particular dual purpose plant is strongly influenced by the costs and mode of operation of both the coupled plant and the national power grid. It is, therefore, not possible to be definite about the cost of steam in such cases. However, as an indication of the costs of water produced at such plants the U.K. Atomic Energy Authority and the Central Electricity Generating Board have jointly agreed that under United Kingdom conditions water from such schemes will have a minimum cost of 62d. p.t.g. at the plant. This cost is based on current reactor and desalination plant designs which could be brought into operation in the first half of the 1970s. It is also based on the assumption that the power and water plants are costed at 8 per cent and 7 per cent interest rates respectively, capital is amortised over 20 years and the load factor is 75 per cent. If, however, an interest rate of 6½ per cent had been used, as it has been in assessing costs of water obtained from conventional water schemes, the water cost would be reduced to 58d. p.t.g. Even without any linking costs this still compares very unfavourably with costs of conventional sources.

58. Several problems arise when considering the operation of dual purpose plants. Maintenance of the power producing plant is likely to be carried out during the summer when the electricity demand is lowest but demand for water is not reduced. So additional storage facilities for the desalted water become necessary to cover the maintenance period, thus adding to the cost.

59. A further problem arises from the higher efficiencies achieved with each new power station. An effect of this, made possible by the power grid, is that older stations are operated at a low load factor, being used only to meet peak power demands. To retain such stations in order to operate the desalination plants coupled to them would involve a cost penalty falling on the product water. Nuclear power plants will probably be kept on base load as long as possible, because of their low operating costs. As the load

factor of existing nuclear power stations is about 80 per cent, substantial water storage would be required if a desalination plant was coupled to such a power plant, thus adding to costs.

60. A further consideration arises from the possibility of a technical fault in the distillation plant. If such a failure occurred either the power station would have to he shut down or a dump condenser would have to be provided to handle the waste steam. The use of either of these alternatives would impose additional costs on the product water.

61. These considerations lead to the conclusion that it will be many years before the cost of water from a dual purpose plant on hase load operation will be reduced to a level which will make it competitive with water ohtained from natural resources, even if the public were prepared to accept some extra cost for desalted water to save the flooding of land, he it of agricultural or amenity value. Further, there are only one or two areas where the demands for water are rising at a rate sufficient to justify the sudden introduction of a hase lcad supply of, say, 100 m.g.d. Therefore the massive schemes being considered in the United States and elsewhere are not applicahle to United Kingdom conditions. When base load desalination by a dual purpose plant becomes economic, it will probably be plants of 10–30 m.g.d. that are required.

Low load factor plants

62. There may be greater potential for the use of low load factor plants before hase load desalination comes into use. It is common practice to use reservoirs to store water for use during drier periods or to regulate the flow of rivers. An advantage of desalination is that water can he provided almost whenever required. A method of combining hoth conventional and desalination sources could, therefore, have advantages. An example of this is the conjunctive use of desalination with an impounding reservoir.

Conjunctive use

63. The reliahle yield of a reservoir may be defined as the uniform rate at which water may he drawn from the reservoir with an accepted degree of reliability. A failure rate of one or two years in a hundred, based upon a statistical analysis of records, is usually regarded as an acceptable risk. If a rate of supply from the reservoir is chosen which is in excess of the reliable yield, then failure of supply would occur more frequently. This higher failure rate could be reduced to one or two years in a hundred by supplementing the supply from a desalination plant. When the reservoir was below a certain critical level, the rate of draw-off from it would he reduced, and the desalination plant would he hrought into use until the reservoir started to refill. In this way a higher reliahle yield could be ohtained.

64. The Water Research Association have undertaken a first analysis of the principles of the conjunctive use of reservoirs and desalination plants and the results of their work are important. The Association selected, as examples, two reservoirs for which adequate run-off records were availahle.

They were not selected because desalination was thought likely to be economic. In both examples the estimated water costs, with conjunctive use, were well in excess of the costs of present supplies, obtainable from natural sources. The two examples were:—

(i) the Alwen reservoir in North Wales which balances the varying flow into it from its catchment with the regular demand over a period less than twelve months ;

(ii) the Abberton reservoir in Essex which is supplied by pumping from the River Stour and balances supply and demand over a comparatively long period of 3 or 4 years.

65. It was found that the reliable yield of the Alwen reservoir could be increased by 2·5 m.g.d. (23 per cent) by installing a single purpose desalination plant with a capacity of 3·8 m.g.d., operated at a load factor of about 10 per cent. The cost of the extra 2·5 m.g.d., excluding linking costs, was estimated at 57d. p.t.g. about 50 per cent of that of base load desalination using a single purpose plant. For comparison the cost of water from new conventional developments in this area would probably fall between approximately 6–12d. p.t.g., again excluding all linking costs.

66. The reliable yield of the Abberton reservoir could be increased by up to 9 m.g.d. (42 per cent) by use of a 9·9 m.g.d. desalination plant operated at a load factor of 43 per cent. The cost of the extra yield, again excluding linking costs, would be approximately 62d. p.t.g. In neither case would the reliability of the system be impaired by the conjunctive use of desalination.

67. For the Abberton Reservoir, the cost of operating a desalination plant only during the summer was assessed since operation of the desalting unit only when the power demand was low seemed to have advantage. It would have the desirable effect of increasing the C.E.G.B. load factor and at the same time supplementing water resources. It was shown that if low pressure steam was available from 4th February to 13th October each year at a cost of 45d. per thousand lbs. such a system would produce water at the same cost of 62d. p.t.g. as that from a single-purpose system available for use at all times. Cheaper steam would result in lower water costs. Many power stations are off-load between February and October, and hence the cost of steam from a power station would probably be based upon the operating cost of the most efficient off-load power station, plus an allowance for power transmission.

Peak demands

68. Desalination may also be used to augment existing supplies to meet summer peak demands as in Jersey. The capital cost of a low load factor plant can be reduced at the expense of operating costs. If it can thus be reduced below the capital cost of any alternative conventional scheme and the load factor is sufficiently low, then desalination might be cheaper than an alternative conventional supply. The type of installation constructed to meet these peak demands, whether conventional or desalination, would be operated in conjunction with the existing supply system. Summer peak demands are experienced at seaside holiday resorts, and in some cases the linking costs might add little to the production cost.

VII. AMENITY ASPECTS OF DESALINATION PLANTS

69. Desalination is often proposed as an alternative to a conventional scheme against which there are amenity objections. Similar objections, however, are likely to be raised against desalination plants, particularly large distillation plants if it was proposed to site them on the coast even though such plants would require a much smaller area of land than a reservoir. If, however, desalination plants could be located at industrial sites on estuaries, amenity objections would be reduced and furthermore linking costs would probably be lower since the desalting plant is likely to be nearer the demand centre. There are, however, problems associated with operating desalination plants on estuarial waters as previously mentioned.

VIII. CONCLUSIONS

70. The only desalination process in common use for producing fresh water from sea water is distillation. The cost of an all the year round supply from such an installation combined with electricity generation is unlikely to be below 58d. p.t.g. plus linking costs which would bring the total to about 6s. a thousand gallons delivered to a service reservoir reasonably close to the plant. We do not think that such a price is acceptable.

71. We consider that distillation will first become economic when used in conjunction with existing conventional sources. In Guernsey and Jersey special circumstances have already justified the introduction of desalination for public water supply. We have not yet been able to find a situation in England and Wales where the cost of water produced by desalination, even if used in conjunction with existing sources, is acceptable. South East England is the most likely area.

72. We are advised by the U.K. Atomic Energy Authority that the cost of water from distillation plants, at 1967 prices, is likely to fall as research and development continue. However, we consider that the comparable cost of water from conventional schemes will not often exceed 3s. a thousand gallons, at 1967 prices, during the remainder of this century. It is not possible to forecast when the gap between the two prices will be sufficiently small to be acceptable.

73. There are likely to be amenity objections to the siting of large distillation plants on the coast, even though a distillation plant would take up far less land than a reservoir.

74. Reverse osmosis and the secondary refrigerant freezing processes for the desalination of sea water may eventually cost less than distillation. We cannot count on this nor can we forecast when full scale plants will be available if development is successful.

75. There may be isolated situations where the use of electrodialysis or reverse osmosis plants to treat brackish ground water will be economic. However, the quantity of such water in England and Wales is limited, and its exploitation will not add significantly to the total available resources. Nevertheless, applications in suitable situations are being studied by the Board.

76. Reverse osmosis shows promise for the treatment of municipal and industrial effluents.

77. The work of the Board's Desalination Co-ordinating Committee is important. It is the one body where research and application of desalination can be reviewed comprehensively and continuously. The Board look to this Committee to continue to take a lively interest in the development of desalination techniques as a means of contributing to water resources in England and Wales.

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Test cells and ancillary equipment for reverse osmosis membrane research at A.E.R.E., Harwell.

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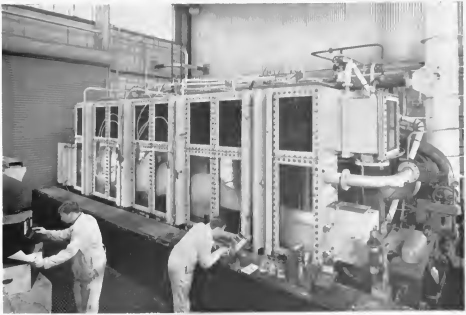

4-stage flash test plant in operation.

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Top tier of 10 stage, 0·046 m.g.d. flash evaporator at Canvey Island on the Thames Estuary.
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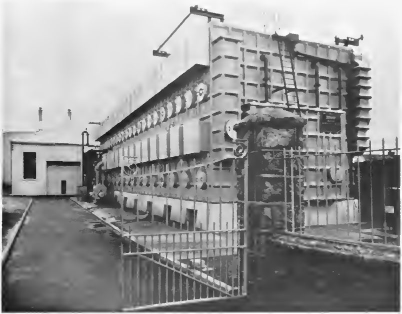

0·5 m.g.d. multi-stage flash plant at Guernsey, Channel Islands. Plants twenty times this size are likely to be the units for the future.

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